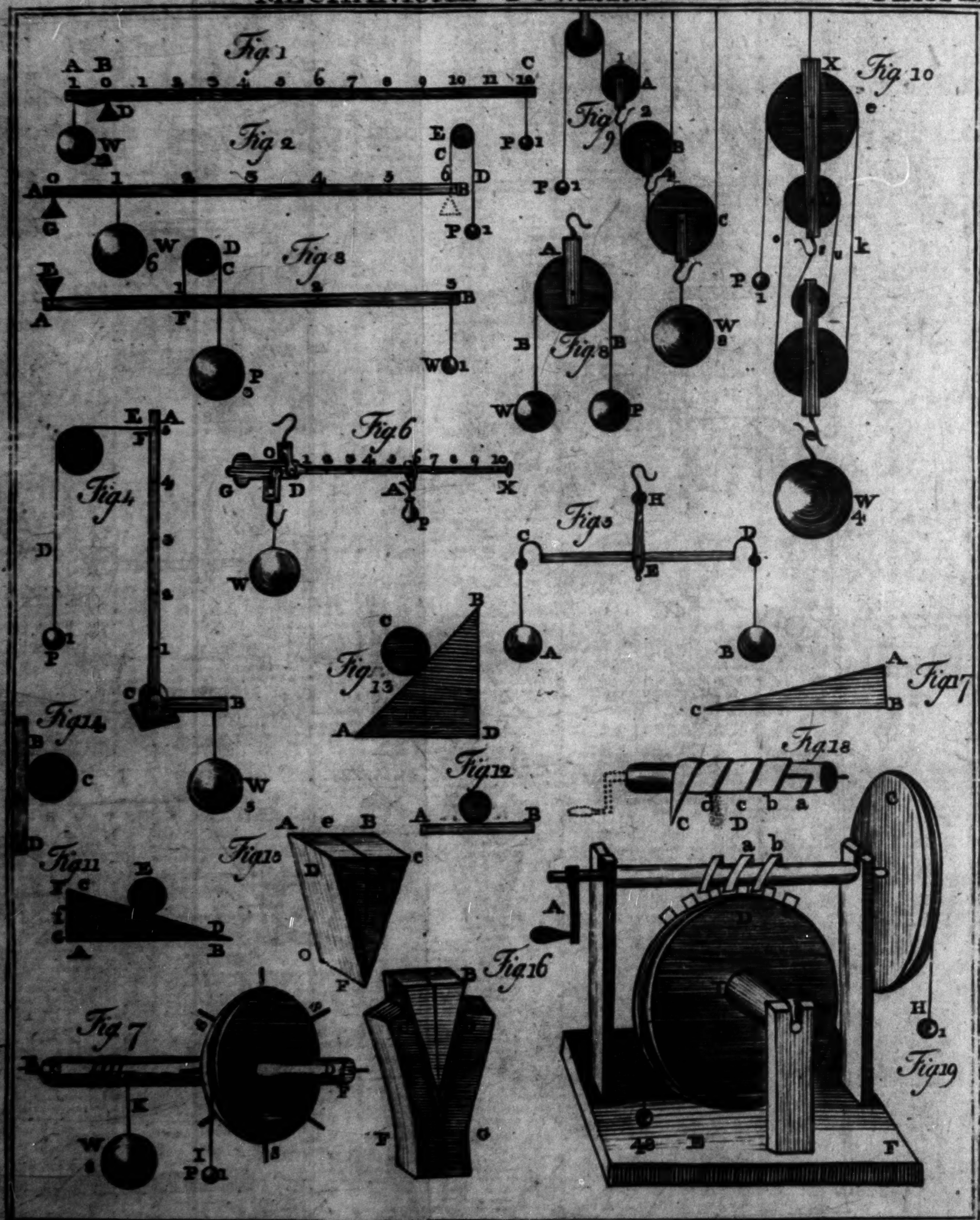
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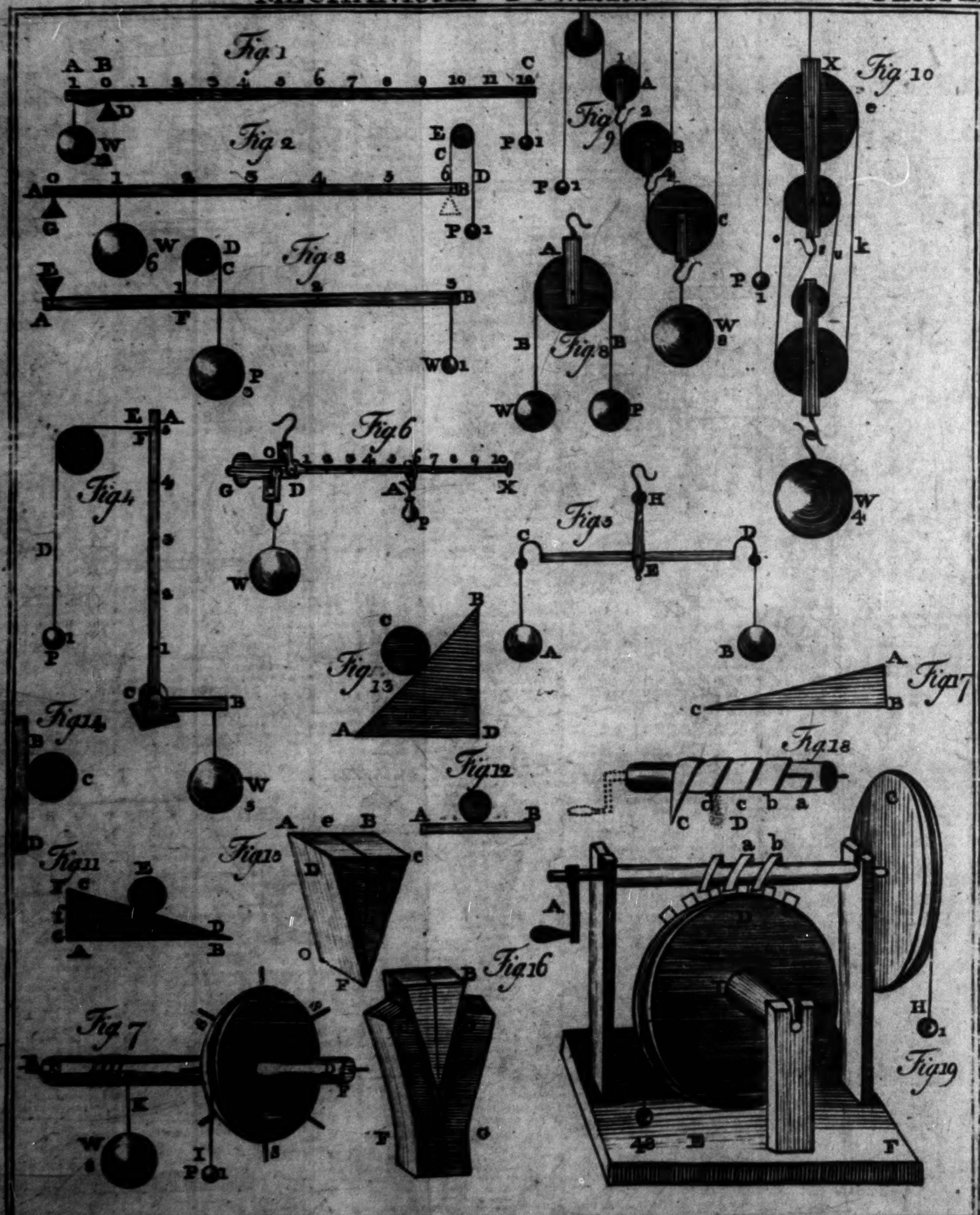

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A

TREATISE

OF THE

MECHANICAL POWERS.

I. OF THE LEVER,	IV. THE SCREW,
II. THE WHEEL AND AXLE,	V. THE WEDGE, AND,
III. THE PULLEY,	VI. THE INCLINED PLANE.

TO WHICH ARE ADDED,

SEVERAL USEFUL IMPROVEMENTS

IN

MILL WORK, BEVEL GEER, FRICTION,

THE BEST SHAPE FOR TEETH IN WHEELS, &c.

By JOHN IMISON.

K

LONDON:
Printed for the AUTHOR,
And ſold by J. Murray, Bookſeller, Nº 32, Fleet Street.

ADVERTISEMENT.

WHEN I published my School of Arts, *or an* Introduction to Useful Knowledge, *I was desired to print a few copies of the mechanical part by itself, in order to oblige some friends who wanted that part only. To comply with their request, is the intention of the present publication; and to render it as serviceable as possible, I have added a few observations concerning Friction, Mill Work, Bevel Geer, &c. which, I hope, will prove useful, and be understood by those for whose information they are principally intended, viz. working mechanics, who have not time or opportunity to peruse larger volumes upon the subjects. I am sorry that I have not yet seen any work or treatise upon the shapes of cycloidical and epicycloidical teeth, or of bevel geer, by which I am prevented from treating so fully on these branches, as I could wish; but I hope soon to collect such information, as to render them familiar. Mr. Ferguson's table for mill-wrights was calculated for* 60 *revolutions of a millstone* 6 *feet diameter per minute, which is considerably too slow; I have therefore made a small alteration in the above table, in proportion to the speed of some of the best mills in the kingdom.*

MECHANICS.

DEFINITIONS.

1. MECHANICS is a ſcience, which treats of the forces, motions, velocities, and in general, of the actions of bodies upon one another. It teaches how to move any given weight with any given power; how to contrive engines to raiſe great weights, or to perform any kind of motion.

2. Body is the maſs or quantity of matter; an elaſtic body is that which yields to a ſtroke, and recovers its figure again. But if not, 'tis called an unelaſtic body.

3. Denſity is the proportion of the quantity of matter in any body, to the quantity of matter in another body of the ſame bigneſs.

4. Force,

4. Force is a power exerted on a body to move it. If it act instantaneously, 'tis called percussion, or impulse. If constantly, 'tis an accelerative force.

5. Velocity is a property of motion, by which a body passes over a certain space in a certain time. And is greater or lesser, as it passes over a greater or lesser space in a certain time as suppose a second.

6. Motion is a continual and successive change of place. If the body moves equally, 'tis called equable or uniform motion. If it increases or decreases, 'tis called accelerated or retarded motion. When it is compared with some body at rest, 'tis called absolute motion. But when compared with others in motion, it is called relative motion.

7. Direction of motion is the course or way the body tends, or the line it moves in.

8. Quantity of motion, is the motion a body has, considered both in regard to its velocity and quantity of matter. This is called the momentum of a body.

9. Vis inertiæ, is the innate force of matter, by which it resists any change, striving to preserve its present state of rest or motion.

10. Gravity is that force wherewith a body endeavours to fall downwards. It is called absolute

gravity in empty ſpace; and relative gravity when immerſed in a fluid.

11. Specific gravity, is the greater or leſſer weight of bodies of the ſame magnitude, or the proportion between their weights. This proceeds from the natural denſity of bodies.

12. Center of gravity, is a certain point of a body; upon which, the body when ſuſpended, will reſt in any poſition.

13. Center of motion, is a fixed point about which a body moves. And the axis of motion is a fixed line it moves about.

14. Power and weight, when oppoſed to one another, ſignify the body that moves another, and the other which is moved. The body which begins and communicates motion is the power; and that which receives the motion, is the weight.

15. Equilibrium is the balance of two or more forces, ſo as to remain at reſt.

16. Machine or engine, is any inſtrument to move bodies, made of levers, wheels, pullies, &c.

17. Mechanic powers, are the lever, wheel, pully, ſcrew and wedge, and the inclined plane.

18. Streſs is the effect any force has to break a beam, or any other body; and ſtrength is the

resistance it is able to make against any straining force.

19. Friction is the resistance which a machine suffers, by the parts rubbing against one another.

POSTULATA.

1. That a small part of the surface of the earth may be looked upon as a plane. For though the earth be round, yet such a small part of it as we have any occasion to consider, does not sensibly differ from a plane.

2. That heavy bodies descend in lines parallel to one another. For though they all tend to a point which is the center of the earth, yet that center is at such a distance that these lines differ insensibly from parallel lines.

3. The same body is of the same weight in all places on or near the earth's surface. For the difference is not sensible in the several places we can go to.

4. Though all matter is rough, and all engines imperfect; yet for the ease of calculation, we must suppose all planes perfectly even; all bodies perfectly smooth; and all bodies and machines to move without friction or resistance; all lines streight and inflexible, without weight or thickness; cords extremely pliable, and so on.

AXIOMS.

1. Every body endeavours to remain in its present ſtate, whether it be at reſt, or moving uniformly in a right-line.

2. The alteration of motion by any external force is always proportionable to that force, and in direction of the right line in which the force acts.

3. Action and re-action, between any two bodies, are equal and contrary.

4. The motion of any body is made up of the ſum of the motions of all the parts.

5. The weights of all bodies in the ſame place, are proportional to the quantities of matter they contain, without any regard to their figure.

6. The vis inertiæ of any body, is proportional to the quantity of matter.

7. Every body will deſcend to the loweſt place it can get to.

8. Whatever ſuſtains a heavy body, bears all the weight of it.

9 Two equal forces acting againſt one another in contrary directions; deſtroys one anothers effects. And unequal forces act only with the difference of them.

10. When

10. When a body is kept in equilibrio; the contrary forces in any line of direction are equal.

11. If a certain force generate any motion; an equal force acting in a contrary direction, will destroy as much motion in the same time.

12. If a body be acted on by any power in a given direction. It is all one in what point of that line of direction, the power is applied.

13. If a body is drawn by a rope, all the parts of the rope are equally stretched. And the force in any part acts in direction of that part. And it is the same thing whether the rope is drawn out at length, or goes over several pullies.

14. If several forces at one end of a lever, act against several forces at the other end; the lever acts and is acted on in direction of its length.

Of the MECHANICAL POWERS.

The foundation of all mechanics.

NOW if we consider bodies in motion, and compare them together, we may do this either with respect to the quantities of matter they contain, or the velocities with which they are moved. For the heavier any body is, the greater is

is the power required either to move or ſtop its motion: and again, the ſwifter it moves, the greater is its force. So that the whole force of a moving body is the reſult of its quantity of matter multiplied by the velocity with which it is moved. And when the product ariſing from the multiplication of the particular quantities of matter in any two bodies by their reſpective velocities are equal, the entire forces are ſo too. Thus, ſuppoſe a body, which we call A, to weigh 40 pounds, and to move at the rate of two miles in a minute; and another body, which we call B, to weigh only 4 pounds, and to move 20 miles in a minute; the entire forces with which theſe two bodies would ſtrike againſt any obſtacle would be equal to each other, and therefore it would require equal powers to ſtop them. For 40 multiplied by 2 gives 80, the force of the body A: and 20 multiplied by 4 gives 80, the force of the body B. upon this eaſy principal depends the whole of mechanics: and it holds univerſally true, that when two bodies are ſuſpended on any machine, ſo as to act contrary to each other; if the machine be put into motion, and the perpendicular aſcent of one body multiplied into its weight, be equal to the perpendicular deſcent of the other body multiplied into its weight, thoſe bodies, how unequal ſoever in their weights, will balance one another in all ſituations: for, as the whole aſcent of one is performed in the ſame time with the whole deſcent of the other, their reſpective velocities muſt be directly as the ſpaces they move through; and the exceſs of weight in one body is compenſated by the exceſs of velocity

in

How to compute the power of any mechanical engine.

in the other. Upon this principal it is eaſy to compute the power of any mechanical engine, whether ſimple or compound; for it is but only finding how much ſwifter the power moves than the weight does (i. e. how much farther in the ſame time) and juſt ſo much is the power increaſed by the help of the engine.

In the theory of this ſcience we ſuppoſe all planes perfectly even, all bodies perfectly ſmooth, levers to have no weight, cords to be extremely pliable, machines to have no friction; and in ſhort, all imperfections muſt be ſet aſide until the theory be eſtabliſhed; and then, proper allowances are to be made.

The Mechanic powers what.

The ſimple machines, uſually called mechanical powers, are ſix in number, viz. the lever, the wheel and axle, the pully, the inclined plane, the wedge, and the ſcrew, they are called mechanical powers, becauſe they help us mechanically to raiſe weights, move heavy bodies, and overcome reſiſtances, which we could not effect without them.

1. A lever is a bar of iron or wood, one part of which being ſupported by a prop, all the other parts turn upon that prop as their center of motion: and the velocity of every part or point is directly as its diſtance from the prop. Therefore, when the weight to be raiſed at one end is to the power applied at the other to raiſe it, as the diſtance of the power from the prop, is to the diſtance of the weight from the prop, the

power

power and weight will exactly balance or counterpoise each other: and as a common lever has next to no friction on its prop, a very little additional power will be sufficient to raise the weight.

There are four kinds of levers. 1st. The common sort, when the prop is placed between weight and power; but much nearer to the weight than to the power. 2. When the prop is at one end of the lever, the power at the other, and the weight between them. 3. When the prop is at one end the weight at the other, and the power applied between them. 4. The bended lever, which differs only in form from the first sort, but not in property. Those of the first and second kind are often used in mechanical engines; but there are few instances in which the third sort is used.

The balance is a streight inflexible rod or beam, turning about a fixed point or axle in the middle of it; to be loaded at each end with weights suspended there; it is by some reckoned a lever of the first kind, but as both its ends are set at equal distances from its center of motion, they move with equal velocities; and therefore, as it gives no mechanical advantage, it cannot properly be reckoned among the mechanical powers. The balance

Let C D be a beam or lever, E the middle point or center of motion; A B, the weights, hanging at the ends C & D, then let the beam and the weights, or the whole machine, be suspended at E; and suppose the beam and the weights be turned upon the center E, then the points C D plate, 1. Fig. 5.

Fig. 5. being equidiſtant from E, will deſcribe equal arches, and therefore their velocities will be equal; and if the bodies A and B be equal, then the motion of A will be equal to the motion of B, as the quantities of matter and velocities are equal; and conſequently, if the beam and weights are ſet at reſt, neither of them can move the other, but they will remain in equilibrio if one weight be greater than the other; that weight and ſcale will deſcend and raiſe the other.

Now the uſe of the balance or a common pair of ſcales, is to compare the weights of different bodies; for any body whoſe weight is required, be put into one ſcale, and balanced by known weights put into the other ſcale, theſe weights will ſhew the weight of the body.

To have a pair of ſcales perfect, they muſt have theſe properties. 1. The points of ſuſpenſion of the ſcales, and the center of motion of the beam C, E, D, muſt be in a right line. 2. The arms C E, D E, muſt be of equal length from the center. 3. That the center of gravity be in the center of motion E. 4. That there be as little friction as poſſible. 5. That they be in equilibrio when empty.

If the center of gravity of the beam be above the center of motion and the ſcales be in equilibrio, if they be put a little out of that poſition, by putting down one end of the beam, that end will continually deſcend until it be ſtopt at the handle H. For by that motion, the center of gravity is

is continually deſcending, according to the nature of it, but if the center of gravity of the beam be below the center of motion; if one end of the beam be put down a little, to deſtroy the equilibrium, it will return back and vibrate up and down. For by the motion the center of gravity is endeavouring to deſcend.

To diſcover a falſe balance, make the weights in the two ſcales to be in equilibrio; then change the weights to the contrary ſcales. And if they be not in equilibrio, the balance is falſe.

Hence alſo to prove a pair of good ſcales, they muſt be in equilibrio when empty, and likewiſe in equilibrio with the two weights. Then if the two weights be changed to the contrary ſcales, the equilibrium will ſtill remain, if the ſcales are good.

Fig. 1. The firſt kind of lever.

A lever of the firſt kind is repreſented by the bar A B C ſupported by the prop D. Its principal uſe is to looſen large ſtones in the ground, or to raiſe great weights to ſmall heights, in order to have ropes put under them for raiſing them higher by other machines. The parts A B and B C on different ſides of the prop D, are called the arms of the lever: the end A of the ſhorter arm A B being applied to the weight intended to be raiſed or to the reſiſtance to be overcome; and the power applied to the end C of the longer arm B C.

In making experiments with this machine, the ſhorter arm A B muſt be as much thicker than

Fig. 1. the longer arm B C, as will be sufficient to balance it on the prop D. This supposed, let P represent a power, whose gravity is equal to 1 ounce, and W a weight whose gravity is equal to 12 ounces. Then, if the power be twelve times as far from the prop as the weight is, they will exactly counterpoise; and a small addition to the power P will cause it to descend and raise the weight W; and the velocity with which the power descends will be to the velocity with which the weight rises, as 12 to 1: that is directly as their distances from the prop; and consequently as the spaces through which they move. Hence it is plain that a man, who by his natural strength, without the help of any machine could support an hundred weight, will by the help of this lever be enabled to support twelve hundred. If the weight be less, or the power greater, the prop may be placed so much farther from the weight; and then it can be raised to a proportionable greater weight. For universally, if the intensity of the weight multiplied into its distance from the prop, be equal to the intensity of the power multiplied into its distance from the prop, the power and weight will exactly balance each other; and a little addition to the power will raise the weight. Thus, in the present instance, the weight W is 12 ounces, and its distance from the prop is 1 inch; and 12 multiplied by 1 is 12; the power P is equal to 1 ounce, and its distance from the prop is 12 inches, which multiplied by 1 is 12 again, and therefore there is an equilibrium between them. So if a power equal to 2 ounces be applied at the distance of 6 inches from

the

the prop, it will juſt balance the weight W; for 6 multiplied by 2 is 12 as before. And a power equal to 3 ounces placed at 4 inches diſtance from the prop would be the ſame; for 3 times 4 is 12; and ſo on in proportion. To this kind of lever may be reduced ſeveral ſorts of inſtruments, ſuch as ſciſſars, pincers, ſnuffers, &c. which are made of two levers acting contrary to one another: this prop or center of motion being the pin which keeps them together. In common practice, the longer end of this lever greatly exceeds the weight of the ſhorter: which gains great advantage, becauſe it adds ſo much to the power.

The Statera or Roman ſteelyard is a lever of this kind, and is uſed for finding the weights of different bodies by one ſingle weight placed at different diſtances from the prop or center of motion D. For, if a weight hangs at A, the extremity of the ſhorter arm D G, is of ſuch a weight as will exactly counterpoiſe the longer arm D X; if this arm be divided into as many equal parts as it will contain, each equal to O D, the ſingle weight P (which we may ſuppoſe to be 1 pound) will ſerve for weighing any thing as heavy as itſelf, or as many times heavier as their are diviſions in the arm D X, or any quantity between its own weight and that quantity. As for example, if P be 1 pound and placed at the firſt diviſion 1 in the arm D X, it will balance 1 pound in the ſcale at W: if it be removed to the ſecond diviſion at 2 it will balance 2 pounds in the ſcale: if to the third, 3 pounds; and ſo on to the end of the arm D X. If each of theſe integral diviſions

Fig. 6. The ſteelyard.

ſions

ſions be ſubdivided into as many equal parts as a pound contains ounces, and the weight P be placed at any of theſe ſubdiviſions, ſo as to counterpoiſe what is in the ſcale, the pounds and odd ounces therein will by that means be aſcertained.

The ſecond kind of lever. A lever of the ſecond kind has the weight between the prop and the power. In this, as well as the former, the advantage gained is as the diſtance of the power from the prop: for the reſpective velocities of the power and weights are in that proportion; and they will balance each other when the intenſity of the power multiplied by its diſtance from the prop is equal to the intenſity of the weight multiplied by its diſtance from the prop. Thus, if A B be a lever on which the weight W of 6 ounces hangs at the diſtance of 1 inch from the prop G, and a power P equal to the weight of 1 ounce hangs at the end B, 6 inches from the prop, by the cord C D going over the fixed pulley E, the power will juſt ſupport the weight: and a ſmall addition to the power will raiſe the weight, 1 inch for every 6 inches that the power deſcends. This lever ſhews the reaſon why two men carrying a burden upon a ſtick between them, bear unequal ſhares of the burden in the inverſe proportion of their diſtances from it. For it is well known, that the nearer either of them is to the burden the greater ſhare he bears of it: and if he goes directly under it he bears the whole. So if one man be at G and the other at B, having the pole or ſtick A B reſting on their ſhoulders; if the burden or weight W be placed five times as near the man at G, as it is

Fig. 2.

to

to the man at B, the former will bear five times as much weight as the latter.

This is likewiſe applicable to the caſe of two horſes of unequal ſtrength to be ſo yoked, as that each horſe may draw a part proportionable to his ſtrength; which is done by ſo dividing the beam they pull, that the point of traction may be as much nearer to the ſtronger horſe than to the weaker, as the ſtrength of the former exceeds that of the latter.

To this kind of lever may be reduced oars, rudders of ſhips, doors turning upon hinges, cutting knives, which are fixed at the point, &c.

If in this lever we ſuppoſe the power and weight to change places ſo that the power may be between the weight and the prop, it will become a lever of the third kind: in which, that there may be a balance between the power and the weight; the intenſity of the power muſt exceed the intenſity of the weight, juſt as much as the diſtance of the weight from the prop exceeds the diſtance of the power. Thus, let E be the prop of the lever A B, and W a weight of 1 pound, placed 3 times as far from the prop, as the power P acts at F, by the cord C going over the fixed pulley D; in this caſe, the power muſt be equal to three pounds, in order to ſupport the weight of 1 pound.

The third kind of lever.

Fig. 3.

To this ſort of lever are generally referred the bones of a man's arm: for when he lifts a weight

by

by the hand, the muſcle that exerts its force to raiſe that weight is fixed to the bone about one tenth part as far below the elbow as the hand is. And the elbow being the center round which the lower part of the arm turns, the muſcle muſt therefore exert a force ten times as great as the weight that is raiſed.

As this kind of lever is a diſadvantage to the moving power, it is uſed as little as poſſible, but in ſome caſes it cannot be avoided, ſuch as that of a ladder, which being fixed at one end, is by the ſtrength of a man's arm reared againſt a wall.

And in clock-work, where all the wheels may be reckoned levers of this kind, becauſe the power that moves every wheel, except the firſt, acts upon it near the center of motion by means of a ſmall pinion, and the reſiſtance it has to overcome, acts againſt the teeth round its circumference.

The fourth kind of lever. Fig. 4.

The fourth kind of lever differs nothing from the firſt but in being bended for the ſake of convenience, A C B is a lever of this ſort bended at C, which is a prop or center of motion. P is a power acting upon the longer arm A C at F, by means of the cord D E going over the pulley G, and W is a weight or reſiſtance acting upon the end B of the ſhorter arm C B. If the power is to the weight as C B is to C F they are in equilibrio. Thus, ſuppoſe W to be 5 pounds acting at the diſtance of one foot from the center of motion C, and P to be 1 pound acting at F, five feet from the

the center C, the power and weight would juſt balance each other. A hammer drawing a nail is a lever of this ſort.

2. The ſecond mechanical power is the wheel and axle, in which the power is applied to the circumference of the wheel, and the weight is raiſed by a rope which coils about the axle as the wheel is turned round. Here it is plain that the velocity of the power muſt be to the velocity of the weight, as the circumference of the wheel is to the circumference of the axle: and conſequently, the power and weight will balance each other, when the intenſity of the power is to the intenſity of the weight, as the circumference of the axle is to the circumference of the wheel. Let A B be a wheel, C D its axle, and ſuppoſe the circumference of the wheel to be 8 times as great as the circumference of the axle; then, a power P equal to 1 pound hanging by the cord I, which goes round the wheel, will balance a weight W of 8 pounds hanging by a rope K which goes round the axle. And as the friction on the pevets or gudgeons of the axle E F is but ſmall, a ſmall addition to the power will cauſe it to deſcend, and raiſe the weight: but the weight will riſe with only an eight part of the velocity wherewith the power deſcends, and conſequently, through no more than an eighth part of an equal ſpace in the ſame time. If the wheel be pulled round by the handles S, S, the power will be increaſed in proportion to their length. And by this means,

The wheel and axle

Fig. 7.

Fig. 7. any weight may be raiſed as high as the operator pleaſes.

To this ſort of engine belong all cranes for raiſing great weights; and in this caſe, the wheel may have cogs all round it inſtead of handles, and a ſmall lanthorn or trundle may be made to work in the cogs, and be turned by a winch; which will make the power of the engine to exceed the power of the man who works it, as much as the number of revolutions of the winch exceeds thoſe of the axle D, when multiplied by the exceſs of the length of the winch above the length of the ſemidiameter of the axle, added to the ſemidiameter or half thickneſs of the rope K, by which the weight is drawn up. Thus, ſuppoſe the diameter of the rope and axle taken together to be 13 inches, and conſequently, half their diameters to be 6 inches 1-half; ſo that the weight W will hang at 6 inches 1-half perpendicular diſtance from below the center of the axle. Now, let us ſuppoſe the wheel A B which is fixed on the axle, to have 80 cogs, and to be turned by means of a winch 6 inches 1 half long, fix'd on the axle of a trundle of eight ſtaves or rounds, working in the cogs of the wheel. Here it is plain, that the winch and trundle would make 10 revolutions for one of the wheel A B, and its axis D, on which the rope K winds in raiſing the weight W; and the winch being no longer than the ſum of the ſemidiameters of the great axle and rope, the trundle could have no more power on the wheel, than a man could have by pulling it round by the edge, becauſe

becauſe the winch would have no greater velocity than the edge of the wheel has, which we here ſuppoſe to be ten times as great as the velocity of the riſing weight; ſo that, in this caſe, the power gained would be as 10 to 1. But if the length of the winch be 13 inches, the power gained will be as 20 to 1: if 19 inches 1-half (which is long enough for any man to work by) the power gained would be as 30 to 1; that is, a man could raiſe 30 times as much by ſuch an engine, as he could do by his natural ſtrength without it, becauſe the velocity of the handle of the winch would be 30 times as great as the velocity of the riſing weight.

The abſolute force of any engine being in proportion of the velocity of the power to the velocity of the weight raiſed by it. But then, juſt as much power or advantage as is gained by the engine, ſo much time is loſt in working it.

In theſe ſort of machines it is requiſite to have a ratchet wheel on the end of the axle C, with a catch to fall into its teeth, which will at any time ſupport the weight, and keep it from deſcending, if the perſon who turns the handle ſhould, through inadvertency or careleſſneſs quit his hold while the weight is raiſing. Thus by this means, the danger is prevented, which might otherwiſe happen by the running down of the weight when left at liberty.

The third mechanical power or engine, conſiſts either of one moveable pulley, or a ſyſtem of The pulley. Fig. 8.

of pullies; ſome in a block or caſe which is fixed, and others in a block which is moveable, and riſes with the weight. For though a ſingle pulley that only turns on its axis, and moves not out of its place, may ſerve to change the direction of the power, yet it can give no mechanical advantage thereto; but is only as the beam of a balance, whoſe arms are of equal length and weight. Thus, A is a ſingle pulley, and if it ſupport the equal weights P and W, the cord B B to which they are appended, is equally ſtretched throughout, and the pulley A ſuſtains both the weights, or is drawn with a force equal to twice P. It is properly, but another form of the balance.

Fig. 9. A combination of 3 moveable pullies A, B, C, connected by three diſtinct cords, each faſtened at one end to an immoveable block above. The power of the whole is diſcovered by ſuppoſing two ſuch weights P and W ſuſpended, as will keep the machine in equilibrio, and then beginning with the leaſt weight, or power P, and conſidering what force each ſeparate pulley ſuſtains. Thus, if P be one pound, the cord which ſuſtains it, acts at its other end upon the fixed block above, and is conſequently reacted upon by the block with a force equal to one pound, and the pulley A, as in fig. 8, is drawn with a force equal to two pounds.

By tracing the ſecond cord in the ſame manner, it will appear that the pulley B is drawn with twice the force of A, or 4 pounds. And C is

drawn

drawn with twice the force of B, or 8 pounds. So that the purchase of this machine is such, that the weight W is 8 times the power P.

The velocity of the weight to that of the power, is a similar way of arguing. Thus, if P descend 8 inches, A will ascend 4; B, 2; and C or W 1 inch; so that the velocities are reciprocally as the power and weight as in the lever.

Another combination of pullies, whereof two, A and B, run in the fixed block X. And two others, C and D, in a moveable block, which raise the weight W, by pulling the cord at P, which goes successively over the pullies A, D, B, C, and is fastened to the fixed block at S. The purchase of this machine is known by considering that the cord is equally stretched throughout, by putting two such weights P and W, as will counterpoise each other. For P is sustained by the single cord, and W by four fold of the same, viz. by the parts o, s, u, k, so that if P be one pound, W will be four pounds. Fig. 10.

The velocity of the power is to that of the weight as four to one. For if P descend four inches, the parts of the cord at k will ascend towards e four inches, and all the other parts of the cord, from the pulley C, will equally follow each other, and C or W will ascend one inch towards s; or the four parts of the cord o, s, u, k, will each be shortened one inch.

In like manner may the purchase of any other combination

combination of pullies be determined. And it will always happen, that the momenta of the weight and power will be equal, as in the other mechanical powers. That is, if any power will raiſe one pound with a certain velocity, it will raiſe two pounds with half that velocity, or one hundred pounds with one hundred part of that velocity, &c. &c.

But as a ſyſtem of pullies has no great weight, and lies in a ſmall compaſs, it is eaſily carried about; and can be applied, in a great many caſes, for raiſing weights, where other engines cannot. But they have a great deal of friction on three accounts: 1. Becauſe the diameters of their axis bear a very conſiderable proportion to their own diameters: 2. Becauſe in working they are apt to rub againſt one another, or againſt the ſides of the blocks: 3. Becauſe of the ſtiffneſs of the ropes that goes over and under them.

The inclined plane. The fourth mechanical power is the inclined plane, and the advantage gained by it, is as great as its length exceeds its perpendicular height. Let A B be a plane parallel to the horizon, and C D a plane inclined to it, and ſuppoſe the whole length C D to be three times as great as the perpendicular height G f F: in this caſe the cylinder E will be ſupported upon the plane C D, and kept from rolling down upon it, by a power equal to a third part of the weight of the cylinder. Therefore, a weight may be rolled up this inclined plane with a third part of the power which would be ſufficient to draw it up by the

Fig. 11.

the ſide of an upright wall. If the plane was four times as long as high, a fourth part of the power would be ſufficient; and ſo on in proportion. Or if a weight was to be raiſed from the floor A B, by means of the machine A B C D (which would then act as a half wedge, and where the reſiſtance gives way only to one ſide) the inclined plane and weight would be in equilibrio when the power applied at G F was to the weight to be raiſed, as G F to G B; and if the power be increaſed; ſo as to overcome the friction of the machine (or half wedge) againſt the floor and weight, the machine will be driven and the weight raiſed: and when the machine has moved its whole length upon the floor, the weight will be raiſed to the whole height from G to F.

The force wherewith a rolling body deſcends upon an inclined plane, is to the force of its abſolute gravity, by which it would deſcend perpendicularly in a free ſpace, as the height of the plane is to its length. For, ſuppoſe the plane A B to be parallel to the horizon, the cylinder will keep at reſt upon any part of the plane where it is laid. If the plane be ſo elevated, that its perpendicular height from D is equal to half its length A B, the cylinder C will roll down upon the plane with a force equal to half its weight, for it would require a power (acting in the direction of A B) equal to half its weight to keep it from rolling. If the plane D B be elevated, ſo as to be perpendicular to the horizon, the cylinder C would deſcend with its whole force of gravity, becauſe the plane contributes nothing to its ſupport or hindrance

Fig. 12.

Fig. 13.

Fig. 14.

rance, and therefore it would require a power equal to its whole weight to keep it from descending. To the inclined plane may be reduced all hatchets, chisels, and other edge tools, which are chamfered only on one side.

The wedge. Fig. 15. The fifth mechanical power or machine is the wedge which may be considered as two equally inclined planes D E F, and C E F joined together at the bases e E F O: then D C is the whole thickness of the wedge at its back A B C D, where the power is applied: E F is the depth or height of the wedge: D F the length of one of its sides, equal to C F the length of the other side; and O F is its sharp edge, which is entered into the wood intended to be split by the force of a hammer or
Fig. 16. mallet striking perpendicular on its back. Thus, A B is a wedge driven into the cleft C E D of the wood F G.

When the wood does not cleave at any distance before the wedge, there will be an equilibrium between the power impelling the wedge downward, and the resistance of the wood acting against the two sides of the wedge, when the power is to the resistance, as half the thickness of the wedge at its back is to the length of either of its sides: because the resistance then acts perpendicular to the sides of the wedge. But, when the resistance on each side acts parallel to the back, the power that balances the resistances on both sides will be as the length of the whole back of the wedge is to double its perpendicular height.

When

When the wood cleaves at any diſtance before the wedge (as it generally does) the power impelling the wedge will not be to the reſiſtance of the wood, as the length of the back of the wedge is to the length of both its ſides; but as half the length of the back is to the length of either ſide of the cleft, eſtimated from the top or acting part of the wedge. For if we ſuppoſe the wedge to be lengthened from the top down to the bottom of the cleft at E, the ſame proportion will hold; namely, that the power will be to the reſiſtance, as half the length of the back of the wedge is to the length of either of its ſides: or which amounts to the ſame thing as the whole length of the back is to the length of both the ſides.

The wedge is a very great mechanical power, ſince not only wood, but even rocks can be ſplit by it; which would be impoſſible to effect by the lever, wheel, and axle, or pulley: for the force of the blow, or ſtroke, ſhakes the cohering parts, and thereby make them ſeparate the more eaſily.

The ſixth and laſt mechanical power is the ſcrew, which cannot properly be called a ſimple machine, becauſe it is never uſed without the application of a lever or winch to aſſiſt in turning it: and then it becomes a compound engine of a very great force, either in preſſing the parts of bodies cloſer together, or in raiſing great weights. It may be conceived to be made by cutting a piece of paper, A B C, into the form of

The ſcrew.

Fig. 17.

Fig. 18. an inclined plane or half wedge, and then wrapping it round a cylinder; and here it is evident, that the winch muſt turn the cylinder once round, before the weight of reſiſtance D can be moved from one ſpiral winding to another, as from d to c: therefore, as much as the circumference of a circle deſcribed by the handle of the winch is greater than the interval or diſtance between the ſpirals, ſo much is the force of the ſcrew. Thus, ſuppoſing the diſtance of the ſpirals to be half an inch, and the length of the winch to be twelve inches, the circle deſcribed by the handle of the winch, where the power acts will be 76 inches nearly, or about 152 half inches, and conſequently 152 times as great as the diſtance between the ſpirals: and therefore a power at the handle, whoſe intenſity is equal to no more than a ſingle pound, will balance 152 pounds acting againſt the ſcrew; and as much additional force, as is ſufficient to overcome the friction, will raiſe the 152 pounds; and the velocity of the power will be to the velocity of the weight as 152 to one. Hence it appears, that the longer the winch is, and the nearer the ſpirals are to one another, ſo much the greater is the force of the ſcrew.

A machine for ſhewing the force or power of the ſcrew may be contrived in the following manner: Fig. 19. Let the wheel C have a ſcrew, a b, on its axis, working in the teeth of the wheel D, which ſuppoſe to be 48 in number. It is plain, that for every time the wheel C, and ſcrew a b, are turned round by the winch A, the wheel D, will be moved one tooth by the ſcrew; and therefore,

in 48 revolutions of the winch, the wheel D will be turned once round. Then, if the circumference of a circle, described by the handle of the winch A, be equal to the circumference of the groove e, round the wheel D, the velocity of the handle will be 48 times as great as the velocity of any given point in the groove. Consequently, if a line G, goes round the groove e, and has a weight of 48 pounds hung to it below the pedestal E F, a power equal to 1 pound at the handle will balance and support the weight. To prove this by experiment, let the circumferences of the grooves of the wheels C and D be equal to one another; and then, if a weight H, of one pound, be suspended by a line going round the groove of the wheel C, it will balance a weight of 48 pounds hanging by the line G, and a small addition to the weight H will cause it to descend, and so raise up the other weight.

Experiment

If the line G, instead of going round the groove e, of the wheel D, goes round its axle I, the power of the machine will be as much increased as the circumference of the groove e exceeds the cirference of the axle; which, supposing it to be 6 times, then 1 pound at H will balance 6 times 48, or 288 pounds hung to the line on the axle; and hence, the power or advantage of this machine will be as 288 to 1: that is to say, a man who, by his natural strength, could lift an hundred weight, will

be able to raiſe 288 by this engine. If a ſyſtem of pullies be applied to the cord H, the power would be encreaſed to an amazing exceſs; but it would be here, as in all other mechanical caſes, for the time loſt is always as much as the power gained: becauſe the velocity with which the power moves, will ever exceed the velocity with which the weight riſes, as much as the intenſity of the weight exceeds the intenſity of the power.

Friction The friction of the ſcrew itſelf is very conſiderable: and there are few compound engines but what, upon account of the friction of the parts againſt one another, will require a third part more of power to work them when loaded, than what is ſufficient to conſtitute a balance between the weight and the power.

In the lever, the friction is nothing. In the wheel and axle, it is as ſmall as the diameter of the gudgeons (added to the power required to bend the rope) is leſs than the diameter of the wheel; but it increaſes according to the weight with which the axle is charged. The like might be ſaid of the pullies, if they did not rub againſt one another, or againſt the ſides of the mortices in the block where they are placed. A new rope of 1 inch diameter, going over a pulley 3 inches diameter, and pulled with a force equal to 5 pounds, requires a force of

1 pound

1 pound or upwards to bend it; and a rope 2 inches diameter requires 4 times as much force.

Wood greaſed, or metal oiled, have nearly the ſame friction; and the ſmoother they are, their friction is the leſs. Yet metals may be ſo highly poliſhed, as to have their friction increaſed by the coheſion of their parts.

Wood ſlides eaſier upon the ground in wet weather than in dry; and eaſier than an equal weight of iron in dry weather: but iron ſlides eaſier than wood in wet weather. Iron or ſteel running in braſs has the leaſt friction of any. Lead makes a great deal of reſiſtance. In wood, acting upon wood, greaſe makes the motion at leaſt twice as eaſy. Wheel-naves, greaſed or tarred, go four times as eaſy as when wet. Smooth ſoft wood, moving upon ſmooth ſoft wood, has a friction equal to about a third part of the weight. In rough wood, the friction is almoſt equal to half the weight. In ſoft wood upon hard, or hard upon ſoft, the friction is equal to about a fifth part of the weight.

In poliſhed ſteel, moving upon poliſhed ſteel or pewter, the friction is about a fourth part of the weight; on copper, a fifth part; and on braſs, a ſixth part of the weight. Metals of the ſame ſort have more friction than different ſorts.

In general, the friction increases in the same proportion with the weight. The friction is also greater with a greater velocity; but not so great in proportion as the increase of velocity.

To have the friction of machines as little as possible, they ought to be made of the fewest and simplest parts. The diameters of the wheels and pullies ought to be large, and the gudgeons of the axles as small can be consistent with the required strength. The sides of the pullies ought not to be all over flat, but to have a small rising in the middle, to keep them from rubbing against each other's sides, and against the sides of their mortices, at a distance from their axle. All the cords and ropes ought to be as pliant as possible; and, for that end, rubbed with grease. The teeth of the wheels should just fit and fill the openings, so as not to be squeezed nor shaked therein. All the parts which work into, or upon one another, ought to be smooth; the gudgeons ought just to fit their holes, and the working parts must be greased. The rounds or staves of the trundles may be made to turn about upon iron spindles, fixed in the round end boards, which will take off a great deal of friction.

Let the strength of all the parts be in proportion to the stress they are to bear, so as they may last equally well. He is by no means a perfect mechanic

chanic who only adjufts the ftrength to the ftrefs, if he does not contrive all the parts to laft fo as that one fhall not fail before another.

When any motion is to be long continued, contrive the machine fo, as that the working power may always move to act one way, if it can be done: for this is better and eafier performed, than when the motion is interrupted by the power's being forced to move firft one way and then another; becaufe every new change of motion requires a new additional force to effect it; and a body in motion cannot fuddenly receive a contrary motion without great violence, and danger of tearing the machine to pieces. But, when the nature of the thing requires that a motion fhould fuddenly be communicated to a body, or fuddenly ftopt; let the force act againft fome fpring, to prevent the machine's being damaged by a fudden jolt.

When a machine is moved by two handles, or winches, on the ends of an axle, the handles are fo placed as that when the one is up the other is down; which is the worft way poffible of placing them, fave that of their being both up or down together. For, when a man raifes a weight by means of turning a winch, he lofes half his force when the winch is upward; becaufe he pufhes himfelf as much backward as he pufhes the winch forward;

and

and when the handle of the winch is down, directly below the axle, he loses half his force; because the winch pulls him as much toward it as he pulls it toward him: and, therefore, the greatest effect of his force on the machine is when he either pulls the winch upward, on the side of the axle next to him, or pushes it downward on the side farthest from him. Yet, even in these cases, the pulling force is stronger than the pushing.

In order to remedy this defect as much as possible, the handles should be so placed as to stand at right angles to one another; and then, when there is a man at each handle, the effect of the one man's force will be greatest when the effect of the other man's is least upon the machine. Whereas, in the common way of placing these handles, when the effect of one man's force is the greatest, the other man's is so too; and when the effect of that man's force is the least, so also is the others; which is working at the greatest disadvantage possible.

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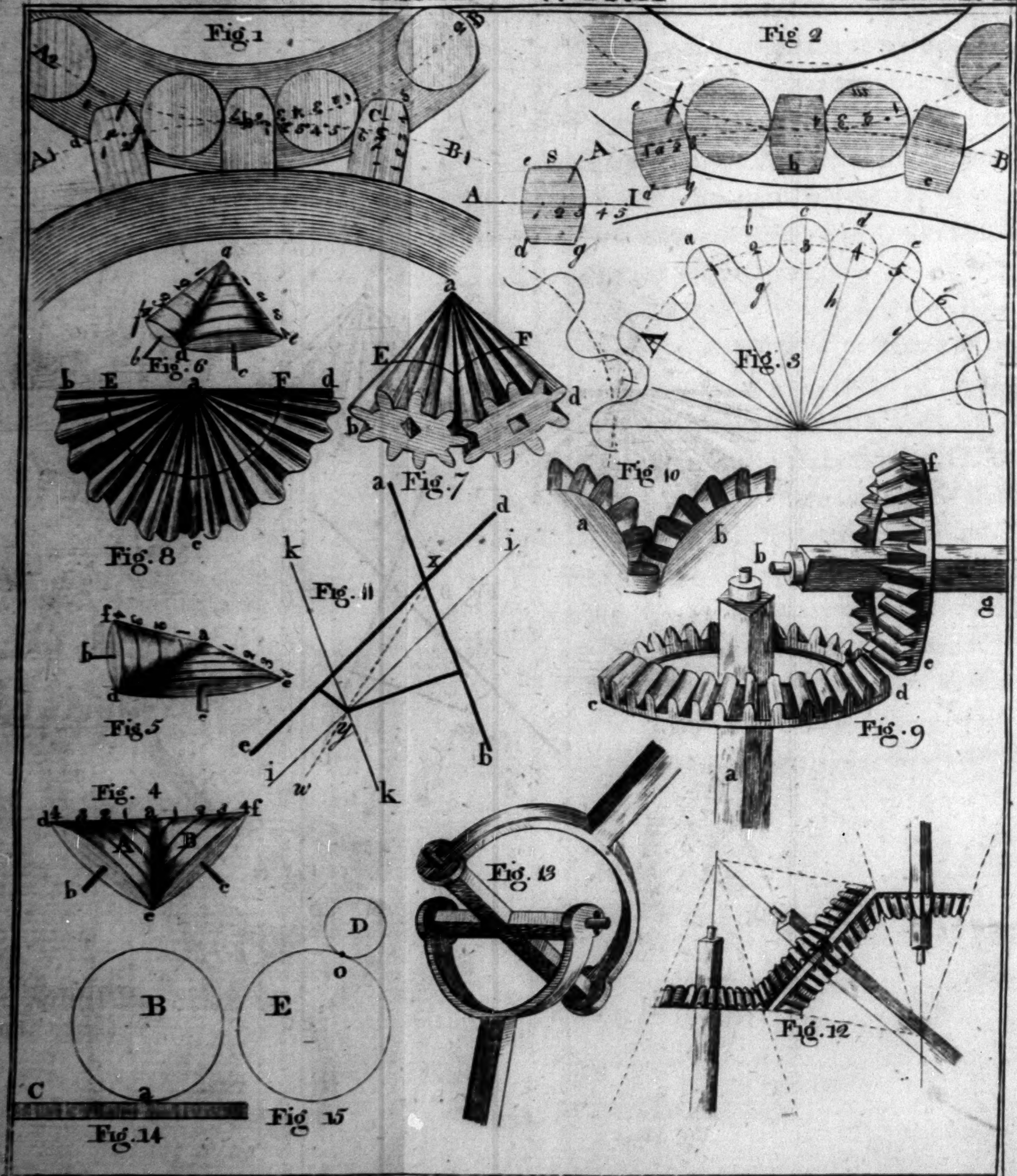
Fig. 1
Fig 2
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Fig 10
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Fig. 12
Fig. 13
Fig. 14
Fig 15

MILL WORK.

In the Conſtruction of Water Mills, it will be neceſſary to obſerve the following Rules.

I. MEASURE the perpendicular height of the fall of water, in feet, above that part of the wheel on which the water begins to act, and call that the height of the fall.

II. Multiply this conſtant number 64,2882 by the height of the fall in feet, and the ſquare root of the product ſhall be the velocity of the water at the bottom of the fall, or the number of the feet that the water there moves per ſecond.

III. Divide the velocity of the water by three, and the quotient ſhall be the velocity of the float boards of the wheel; or the number of feet they muſt each go though in a ſecond, when the water acts upon them ſo as to have the greateſt power to turn the mill.

IV. Divide

IV. Divide the circumference of the wheel in feet by the velocity of its floats in feet per ſecond, and the quotient ſhall be the number of ſeconds in which the wheel turns round.

V. By this laſt number of ſeconds divide 60, and the quotient ſhall be the number of turns of the wheel in a minute.

VI. Divide 120 (the number of revolutions a millſtone 4 1-half feet diameter ought to have in a minute) by the number of turns of the wheel in a minute, and the quotient ſhall be the number of turns the millſtone ought to have by one turn of the wheel.

VII. Then, as the number of turns of the wheel in a minute is to the number of turns of the millſtone in a minute, ſo muſt the number of ſtaves in the trundle be to the number of cogs in the wheel, in the neareſt whole numbers that can be found.

By theſe rules the following table is calculated to a water wheel 18 feet diameter, which, I apprehend, may be a good ſize in general.

To conſtruct a mill by this table, find the height of the fall of water in the firſt column, and againſt that height in the ſixth column, you have the number

ber of cogs in the wheel, and ſtaves in the trundle, for cauſing the millſtone 4 feet 6 inches diameter, to make about 120 revolutions in a minute, as near as poſſible, when the wheel goes with 1-third part of the velocity of the water. And it appears by the 7th column, that the number of cogs in the wheel, and ſtaves in the trundle, are ſo near the truth for the required purpoſe, that the leaſt number of revolutions of the millſtone in a minute, is 118, and the greateſt number never exceeds 121; which is according to the ſpeed of ſome of the beſt mills I have yet ſeen.

1. A leſs quantity of water will turn an overſhot, than what will turn an underſhot or breaſt wheel; as an overſhot is actuated by the ſtatical weight, or gravity, and the underſhot or breaſt, by impulſe only; ſo that where there is but a ſmall quantity of water, and a fall great enough for the wheel to lie under it, the overſhot wheel is always uſed. But where there is a large body of water, and little fall, the underſhot wheel muſt take place. Where the water runs only upon a little declivity, it can act but ſlowly upon the under part of the wheel; in which caſe, the motion of the wheel will be very ſlow: and therefore, the float-boards ought to be very long, though not high, that a large body of water may act upon them; ſo that what is wanting in velocity, may be made up in power: and then the cog-

wheel may have a greater number of cogs, in proportion to the rounds in the trundle, in order to give the millstone a sufficient degree of velocity.

The Mill Wright's Table.

Height of the fall of water.	Velocity of the fall of water per second.		Velocity of the wheel per second.		Revolutions of the wheel per minute.		Revolution of the millstone for one of the wheel		Cogs in the wheel, and staves in the trundle		Revolutions of the millstone per minute by these staves and Cogs.	
Feet.	Feet.	100 parts of a foot.	Feet.	100 parts of a foot.	Revolutions.	100 parts of a rev.	Revolutions.	100 parts of a rev.	Cogs.	Staves.	Revolutions.	100 parts of a rev.
1	8	02	2	67	2	83	42	40	254	6	119	84
2	11	34	3	78	4	00	30	00	210	7	120	00
3	13	89	4	63	4	91	24	44	196	8	120	28
4	16	04	5	35	5	67	21	16	190	9	119	74
5	17	93	5	98	6	34	18	92	170	9	119	68
6	19	64	6	55	6	94	17	28	156	9	120	20
7	21	21	7	07	7	50	16	00	144	9	120	00
8	22	68	7	56	8	02	14	96	134	9	119	34
9	24	05	8	02	8	51	14	10	140	10	119	14
10	25	35	8	45	8	97	13	38	134	10	120	18
11	26	59	8	86	9	40	12	76	128	10	120	32
12	27	77	9	26	9	82	12	22	122	10	119	80
13	28	91	9	64	10	22	11	74	118	10	120	36
14	30	00	10	00	10	60	11	32	112	10	118	72
15	31	05	10	35	10	99	10	92	110	10	120	96
16	32	07	10	09	11	34	10	58	106	10	120	20
17	33	06	11	02	11	70	10	26	102	10	119	34
18	34	02	11	34	12	02	9	98	100	10	120	20
19	34	95	11	65	12	37	9	70	98	10	121	22
20	35	86	11	95	12	68	9	46	94	10	119	18
1	2		3		4		5		6		7	

The

The Method for ſetting out a Spur Wheel and Wallower.

DRAW the pitch lines A 1, B 1, A 2, 2 B; then divide them into the number of teeth or cogs required as a b c. Plate II. Fig. 1.

Divide one of thoſe diſtances, as b c, into ſeven equal parts, as 1, 2, 3, 4, 5, 6, 7; three parts allow for the thickneſs of the cogs, as 1, 2, 3 in the cog a, and four for the thickneſs of the ſtave of the wallower (one reaſon for allowing three parts for the cog, and four for the ſtave, is, the wallower is in general of leſs diameter than the wheel, therefore ſubject to more wear in proportion of the number of cogs, to the number of ſtaves; but if there is the ſame number of ſtaves as of cogs, they may be of equal thickneſs) as 1, 2, 3, 4, in the ſtave m, Fig. 2; the height of the cog is equal to four parts; then divide its height into five equal parts, as 1, 2, 3, 4, 5, in the cog C; allow three for the bottom to the pitch line of the cog; the other two parts for the epicycloid, ſo as to fit and bear on the ſtave equally. The millwrights in general put the point of a pair of compaſſes in the dot 3. of the cog a, and ſtrike the

line d, e; then remove the point of the compaſſes to the point d, and ſtrike the curve line 3 f, which they account near enough the figure of the epicycloid.

Fig. 2. The method for a face wheel is thus; divide the pitch line A B into the number of cogs intended, as a b c; divide the diſtance b c, into ſeven equal parts; three of thoſe parts allow for the thickneſs of the cogs, as 1, 2, 3 in the cog a, four for the height, and four for the width as d e, and four for the thickneſs of the ſtave, as 1, 2, 3, 4 in the ſtave m; draw a line through the center of the cog, as the line A I, at S; and on the point 5, deſcribe the line d e; remove the compaſſes to the point A, and draw the line f g, which forms the ſhape of the cog; then ſhape the cog on the ſides to a cycloid, as d e f g, Fig. 1. But this method of ſetting out the ſhape of a cog is variable according to the cycloid in different diameters of wheels.

In common ſpur nuts, divide the pitch line A, into twice as many equal parts as you intend teeth, as a, b, c, d, e; with a pair of compaſſes opened to Fig. 3 half the diſtance of any of thoſe diviſions, from the points a 1, c 3, e 5, draw the ſemicircles a, c, and e, which will form the ends of the teeth. From the points 2, 4, and 6 draw the ſemicircles g h i, which will form the hollow curves for the ſpaces; but if the

the ends of the teeth were epicycloids instead of semicircles, they would act much better.

The Principle of Bevel Geer.

CONSISTS of two cones, rolling on the surface of each other, as the cone A and B revolving on their centers a b, a c, if their bases are equal, will perform their revolutions in one and the same time, or any other two points equally distant from the center a, as d 1, d 2, d 3, &c. will revolve in the same time as f 1, f 2, f 3, &c. In the like manner, if the cones, a d e, be twice the diameters at the base d e, as the cones a f d are, then if they turn about their centers, when the cone a f d has made one revolution, the cone a d e will have made but half a revolution; or when a f d has made two revolutions, a d e will have made but one, and every part equally distant from the center a, as f 1, f 2, f 3, &c. will have made two revolutions to e 1, e 2, e 3, &c. and if the cones were fluted, or had teeth cut in them, diverging from the center a, to the bases d c, e f, they would then become bevel geer. The teeth at the point of the cone being small

Bevel Geer. Fig. 4.

Fig. 5 and 6.

Fig. 7. and 8

Fig. 8, and 9. ſmall and of little uſe, may be cut off at E and F, Fig. 8, as ſeen by Fig. 9, where the upright ſhaft, a b, with the bevel wheel, c d, turns the bevel wheel, e f, with its ſhaft b g, and the teeth work Fig. 10. freely into each other, as a b Fig. 10. The teeth may be made of any dimenſion, according to the ſtrength required; and this method will enable them to overcome a much greater reſiſtance, and work ſmoother than a face wheel and wallower of the common form can poſſibly do; beſides, it is of great uſe to convey a motion in any direction, or to any part of a building with the leaſt trouble and friction.

The method of conveying motion in any direction, and proportioning or ſhaping the wheels thereto, Fig. 11. is as follows: let the line a b, repreſent a ſhaft coming from a wheel; draw the line c d to interſect the line a b, in the direction, that the motion to be conveyed is intended, which will now repreſent a ſhaft to the intended motion.

Again, ſuppoſe the ſhaft c d is to revolve three times, whilſt the ſhaft a b revolves once, draw the parallel line i i, at any diſtance not too great, ſuppoſe 1 foot by a ſcale, then draw the parallel line k k at 3 feet diſtance, after which, draw the dotted line w x, through the interſection of the ſhafts a b, and c d, and likewiſe through the interſection of the parallel lines i i and k k, in the

points

points x and y; which will be the pitch line of the two bevel wheels, or the line where the teeth of the two wheels act on each other, as may be feen Fig. 12, where the motion may be conveyed in any direction. Fig. 12.

The univerfal joint, as reprefented, may be applied to communicate motion inftead of bevel geer, where the angle does not exceed 30 or 40 degrees, and the equality of motion is not regarded, for as it recedes from a right line, its motion becomes more irregular. This joint may be conftructed by a crofs, as reprefented in the figure; or with four pins faftened at right angles upon the circumference of a hoop, or folid ball. Univerfal Joint. Fig. 13.

To defcribe the Cycloid and Epicycloid.

IF a point or pencil a, on the circumference of the circle B, proceeds along the plane a C, in a right line, and at the fame time revolves round its center, it will defcribe a cycloid. Fig. 14.

And, if the generating circle D, moves along the circumference of another circle E, and at fame time turns round its center, the point o, will defcribe an epicycloid. Fig. 15